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Properties of InP self-assembled quantum dots embedded in $\text{In}_{0.49}(\text{Al}_x\text{Ga}_{1-x})_{0.51}\text{P}$ grown by metalorganic chemical vapor deposition

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III-Phosphide self-assembled quantum dot (SAQD or simply QD) structures offer the potential to realize injection lasers operating in the visible spectral region with improved performance characteristics such as low threshold current density, high characteristic temperature, and high differential gain. Also, SAQD growth can overcome the limitation of lattice matching between the substrate and the epitaxial active region due to the intrinsic nature of the growth mode (i.e., strain-induced S-K growth).

InP quantum dots have been grown and characterized on direct-bandgap $\text{In}_{0.49}\text{Ga}_{0.51}\text{P}$ matrices by several research groups and on indirect-bandgap $\text{In}_{0.49}\text{Al}_{0.51}\text{P}$ matrices by these authors. As expected, the growth characteristics and optical properties are different in these cases. In this study, we report the characteristics of InP SAQDs embedded in $\text{In}_{0.49}(\text{Al}_x\text{Ga}_{1-x})_{0.51}\text{P}$ grown by low-pressure metalorganic chemical vapor deposition (LP-MOCVD) to make a complete bridge between two material systems. The InP QD growth studies are done at a temperature of $\sim 650^\circ\text{C}$ by altering growth times and using various $\text{In}_{0.49}(\text{Al}_x\text{Ga}_{1-x})_{0.51}\text{P}$ matrices ($x = 0.0, 0.3, 0.6$, and 1.0). The morphology changes (average sizes and densities) of the exposed SAQDs (grown without the upper cladding layer), depend on the growth time and the matrix material, and are characterized by atomic force microscopy (AFM). As the growth time increases from the "planar-layer-growth equivalent" of 7.5 MLs to 15 MLs for InP/ $\text{In}_{0.49}(\text{Al}_{0.6}\text{Ga}_{0.4})_{0.51}\text{P}$ quantum dot structures, the dominant QD size increases, while the densities remain almost the same ($\sim 1\text{--}2 \times 10^8$ dots/ mm^{-2}) and the dominant heights are $\sim 10\text{--}25$ nm, depending on growth time.

Photoluminescence (PL) spectra were taken at 4 K and 300 K to determine the light-emitting characteristics of the $\text{In}_{0.49}(\text{Al}_x\text{Ga}_{1-x})_{0.51}\text{P}$ quantum-dot heterostructures (QDHs). 4 K PL spectra from the InP SAQDs embedded in $\text{In}_{0.49}(\text{Al}_x\text{Ga}_{1-x})_{0.51}\text{P}$ cladding layers exhibit PL emission in the visible orange and red spectral regions. Emission peaks appear at higher energy for shorter growth times and higher bandgap matrices — 2.10 eV, 1.90 eV, and 1.82 eV peak energies for 3.75, 7.5, and 15 ML InP/ $\text{In}_{0.49}(\text{Al}_{0.6}\text{Ga}_{0.4})_{0.51}\text{P}$ QDH, while emission peaks occur at 2.06 eV, 1.92 eV, and 1.87 eV for 7.5, 11.25, and 15 ML InP/ $\text{In}_{0.49}\text{Al}_{0.51}\text{P}$ QDH, respectively. Since the bandgap of the "active" InP SAQDs is modified by multi-dimensional quantum confinement, bulk material properties like the band offset do not apply in this case. We further study the InP/ $\text{In}_{0.49}(\text{Al}_x\text{Ga}_{1-x})_{0.51}\text{P}$ ($x = 0.6$) SAQDs using ballistic electron emission microscopy (BEEM) techniques to

determine the band structure of the dots. Also, transmission electron microscopy (TEM) is used to characterize the microscopic material quality and morphology of the individual QD and the interfaces between SAQD and cladding layers. Defect-free SAQDs are observed for the height of less than ~ 30 nm. Furthermore, we have achieved 300 K lasing from InP SAQDs at the shortest wavelength yet reported for III-P QDs.

In summary, we will report on the optical, structural, and electronic properties of InP SAQDs embedded in $\text{In}_{0.49}(\text{Al}_x\text{Ga}_{1-x})_{0.51}\text{P}$ layers grown on GaAs substrates by MOCVD.